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Executive Officer and Members of the Board
California Regional Water Quality Control Board
San Francisco Region
1515 Clay Street, Suite 1400
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Re: Response to Talking Points for NRDC Meeting, January 29, 2008

Dear Mr. Wolfe and Members of the Board:

The primary purpose of this letter is to respond to the issues raised by Regional Water Board staff in the "Talking Points for NRDC Meeting, January 29, 2008" document ("Talking Points"). Many of the points raised address existing performance at development sites in the San Francisco Bay Area under MS4 regulations and assert that these existing requirements can collectively result in attainment of the 5 percent EIA standard proposed for adoption in Ventura County. Because these points underscore the practicability of adopting a clear and specific EIA limitation near the 3 percent standard analyzed in my reports, this letter does not address this aspect of the Talking Points. Otherwise, three general criticisms are raised, relating to the infiltration rate, description of building site size and character, and runoff coefficients assumed in my analysis. This letter addresses each criticism, point-by-point, below.

1. INFILTRATION RATE

My analyses assumed, in some instances, an infiltration rate of 0.5 inches per hour: this is an appropriate estimate since it is obtainable in some natural soil conditions and in any scenario in which typical LID techniques are implemented, specifically including soil amendments. The argument advanced in the Talking Points that infiltration rates are likely to be below those I relied on my analyses is not well-taken for a number of reasons:

1. The SCS (now NRCS) soil surveys cited in the Talking Points, which in some instances postulate infiltration rates lower than those I relied upon in some aspects of my analyses, are performed at much larger than site-specific scales and often mischaracterize site soils. Hence, soils at a given site are frequently categorized incorrectly in the A-D hydrologic soil groupings, a system which itself is quite coarse.

2. Given that the hydrologic soil grouping system is rather coarse, soils are much more variable in the natural environment than suggested by a quarternary breakdown. Actual infiltration rates vary accordingly and are often much different from those tabulated in the Talking Points.

3. Even if less infiltrative soils are encountered at development sites that would be covered by requirements in the MRP, extensive experience around the nation and the world demonstrates that relatively less infiltrative soils can be simply and effectively amended (generally, with organic compost and, sometimes, with other additions to typical depths of 1-2ft.) to increase infiltration rates substantially. These increases occur because the more open amended soil stores water and "meters" it into the underlying soils at a rate they can accommodate. In low-impact site design type "bioretention" cells, with amended soils if necessary, vegetation assists in water loss in several ways: (1) intercepting precipitation and holding it on leaves from which some water evaporates, (2) assisting water's passage into the ground by "piping" it along roots, and (3) taking water from the soil into tissues where it is stored and where some transpires to the atmosphere. Together, these processes can significantly reduce surface runoff discharge. Please see the account on the first monitoring study described in Attachment A for evidence supporting these points.

Infiltration (or, synonymously, hydraulic conductivity) rates for general soils types have been published many times. The published rates generally do not agree with those quoted in the Talking Points. For example, Clapp and Hornberger (1978) tabulated rates for 11 soil types ranging from sand to clay in units of meters/year. Converted to inches/hour, the table values compare to those in the Talking Points as follows:

Soil	Clapp and Hornberger (1978)	Talking Points
Silty clay loam, clay loam, sandy clay silty clay	0.14-0.35	0-0.04
Sandy clay loam	0.9	0.04-0.16
Silt loam, loam	1.0	0.16-0.31
Sandy loam	4.9	0.31-0.47

Clapp and Hornberger's rates for sand and loamy sand exceed 20 inches/hour (compared to 0.31-0.47 in the Talking Points table). The discrepancies for the relatively coarse soils, especially, call into question the whole basis of the table. Anybody who has done field work in soils containing substantial sand, as I have, has observed percolation much more like the rates given by Clapp and Hornberger than the Talking Points table. I would caution that site-specific data should be used instead of published values for general soil types when undertaking design and other engineering analyses. However, the general literature much more strongly supports the rate of 0.5 inch/hour that I used for A and B and, with amendment, C soils. The ability of San Francisco Bay region communities to manage stormwater much more effectively using LID techniques should not be foreclosed on such a flimsy and faulty basis.

The points I raise regarding soil variability and the ability to amend soils to increase infiltration rates are supported by my own research on the City of Seattle's natural drainage systems. The City builds two basic types of what amount to bioretention cells in street-side locations to manage street and neighborhood runoff. One, which the City calls SEA (for Street-Edge Alternatives) Streets, is for relatively flat streets and consists of a series of broad, shallow basins generally having amended soils. The other, for more sloped streets, is similar, except that the cells are separated by weirs to form a series of stepped pools, termed a cascade. Attachment A summarizes the results of these studies. Attachment B lists references to study reports as well as other sources cited in this letter.

The cascade location is in a general area of hydrologic group C soils. Prior to design and construction, the City performed soil testing and hydraulic conductivity measurement at an intermediate point along the approximately 900-foot length of the facility. The resulting infiltration rate was 0.25 inch/hour. It was discovered during construction that mostly sandy soils occur near the discharge end of the cascade, which of course would have a higher infiltration rate. This observation is another example of what I have seen elsewhere: soils can vary radically, even within the confines of a stormwater management device, supporting my first and second points above.

The City amended the cascade soils by placing 1ft. of 70 percent mineral aggregate with 30 percent decomposed organic soil matter in the bed. As demonstrated in the account attached to this letter, the cascade system was highly successful in decreasing runoff, in terms of both rates and overall volumes discharged, converting surface flow to infiltration and evapotranspiration. It was beyond the scope and impossible with the measurements made in the study to separate those two components of the hydrologic balance. Infiltration most likely predominated overall, and certainly in the wet season, but evapotranspiration is thought still to be important and even contributing to surface flow reduction in the winter.

To provide insights for future designs, there was a desire to quantify, at least approximately, what minimum infiltration rate to expect. Rates estimated through analysis of rain and runoff data, as well as with the aid of a simple model (Chapman 2006), demonstrated considerable variability dependent on storm characteristics and soil wetness. To get an idea of the <u>limiting</u> condition (the rate in relatively large, extended storms falling on comparatively wet soils), Table 1 presents examples of rainfall events producing at least 0.9 inch of rain over extended periods and having an antecedent precipitation index[1] in the "wet" range (≥ 0.6). These storms all occurred during the cooler months and thus largely represent infiltration and probably not much evapotranspiration. Infiltration rates were 0.3 or 0.5 inch/hour in all but one of these events, which had two to four times as much rainfall as any other example. We concluded that a rate of 0.3-0.5 inch/hour would be a reasonable, relatively conservative design value.

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[1] The Antecedent Precipitation Index (API) is defined as $API_t = R_{t-1} + k*API_{t-1}$, where API_t is the index for day t, API_{t-1} is the index for the previous day, R_{t-1} is the rainfall depth for the previous day in inches, and k is a coefficient reflecting the relative rate of soil drying (Linsley, Kohler and Paulhus 1982). The value of k can range from approximately 0.85 (sand) to 0.98 (clay). In this study, a k of 0.85 was chosen due to the somewhat sandy nature of the weathered till present at the site.

Table 1. Estimated Infiltration Rates for Relatively Large, Extended Storms in Comparatively Wet Soils

Examples	Storm Characteristics				Volumes					Estimated Infiltration Rates	
	Rainfall	Duration	Antecedent conditions		Outflow	Inflow	Estimated True Inflow	Estimated Infiltration	Estimated Infiltration	Volume Rate[c]	Water Depth Rate[d]
Date(s) of Storm	(inches)	(hours)	API[a]	7-day rain[b]	(ft^3)	(ft^3)	(ft^3)	(ft^3)	(%)	(ft^3/hour)	(inch/hour)
November 17-19, 2003	3.86	51	0.8	0.71	23008	13388	26776	3768	14	45	0.1
January 28-30, 2004	1.64	33	0.6	0.86	10035.8	9134	15070	5034	33	109	0.3
December 9-11, 2004	1.89	37	1.5	1.75	5387	9929	13400	8000	60	177	0.5
April 15, 2005	1.15	23	0.7	0.50	4092	4058	8116	4024	50	175	0.5
November 5, 2005	0.91	14	1.8	2.25	4113	3949	7248	3135	43	115	0.3
January 12-14, 2006	0.98	39	2.7	3.10	855	3460	6800	6000	88	116	0.3
January 29-30, 2006	2.16	26	1.2	0.77	17921	14924	22758	4837	21	188	0.5

[a] Antecedent Precipitation Index.
[b] Rainfall (inches) in the 7 days preceding the storm.
[c] Estimated infiltrated volume, minus 1500ft^3 (42.5m^3) estimated amount of above-ground storage, divided by the storm duration.
[d] Volume infiltration rate (preceding column) spread out over 450ft^2 (418m^2) of channel surface area.

These results—produced by evaluating the wettest conditions, along with the San Fernando Valley study I cited in my report *Initial Investigation of the Feasibility and Benefits of Low-Impact Site Design Practices ("LID") for the San Francisco Bay Area* (the "Initial Report")—offer substantial evidence supporting the 0.5 inch/hour rate that underlies my analysis for land developments and stormwater management facilities on A, B, and C soils in the San Francisco Bay region. Note that amending soils where native soils do not provide that rate, which would be the standard practice on most or all soils truly falling into the C group, also makes my previous analysis appropriate.[1]

I have concluded through my long association with low-impact drainage systems that great runoff attenuation can be achieved, through organic soil amendments, in all but predominantly clay soils. The City of Seattle, which sits largely on glacial till soils with a hardpan layer typically 2 to 4ft. below the surface, has recognized and demonstrated this to be the case, to the considerable benefit of its stormwater management program and receiving waters (please see the attachment). The San Francisco Bay region should take advantage of what has been learned in Seattle and elsewhere and do no less.

2. BUILDING INFORMATION

Contrary to the implication in the Talking Points document, the information about building typologies used in my reports is not inapplicable to the San Francisco Bay Area. While lot sizes and building size do vary between and within communities, the examples used are based on

[1] Please note that I did not apply a 0.5 inch/hour rate to D soils in my report, "Supplementary Investigation of the Feasibility and Benefits of Low-Impact Site Design Practices ("LID") for the San Francisco Bay Area" (the "Supplementary Report"), which was prepared to explore what could be accomplished with low-impact practices suitable for areas with limited infiltration. Those practices rely heavily on water harvesting. It deserves mention, though, that the availability of harvesting techniques, a recognized part of LID techniques, is not limited to projects on D soils. Therefore, even if infiltration rates in some places fell below those I used in my analysis, this fact alone does not make the conclusions in my report unwarranted. Moreover, infiltration rates lower than those I used in my analysis also would not preclude adoption of another, different numerical design requirement for LID, contrary to the implication in the Talking Points document.

empirical data and best professional judgment based on my many decades of work in this field. Considerable information is specific to the Bay Area; for example, parking space size came from a review of several codes, and single-family lot sizes were taken directly from a Bay Area website, http://www.ppic.org/content/other/706EHEP_web_only_appendix.pdf. I further reviewed the sizes I used for driveways, sidewalks, and access roads through additional research. In my analysis, I assumed a single-car driveway to be 10ft. wide. The following websites show that width to be within the range of recommendations: http://www.drivewaytips.com/layout.html and http://www.salina-ks.gov/filestorage/126/198/2521/2883/502/RESDRIVEWAYDESIGNSTANDARDS.pdf. I used a 4-foot width for sidewalks, which is also within the range of recommendations given on the following websites: http://ncbwforum.infopop.cc/eve/forums/a/tpc/f/214603/m/661605534, http://www.lawalks.org/pedSurv/2aV03.htm, and ftp://ftp.odot.state.or.us/techserv/roadway/web_drawings/roadway/pdf/rd740.pdf. I assumed access roads to be 20ft. in width to allow vehicles to pass in each direction. Once again, websites support this dimension: http://www.centralfpd.com/FirePrevention/DistrictRegulations/FPB59HIDDEN/tabid/136/Default.aspx, ftp://ftp-fc.sc.egov.usda.gov/NHQ/practice-standards/standards/560.doc, and http://www.deq.state.mi.us/documents/deq-swq-nps-ar.pdf. This review demonstrates that my selections were entirely realistic and proper.

By contrast, the Talking Points assert, without noting the basis of the assertion, that the assumed quantities are overestimates. Notably, if this were true, it would only make it *easier* to prevent the generation and discharge of surface runoff through LID practices. Therefore, I was conservative in the claims I made in my two reports regarding the potential to attenuate runoff through low-impact site design techniques. I stand by those assessments, from both the standpoints of LID capabilities (infiltration, evapotranspiration, and harvest) and land use characteristics. Moreover, even if one assumed some variation in the characteristics of site conditions, the conclusion of my analysis remains well-supported: there is considerable potential to retain large quantities of precipitation onsite at development projects in the Bay Area.

3. RUNOFF COEFFICIENTS

The Talking Points take issue with my use of a runoff coefficient for pervious areas no higher than 0.12 for the Bay Area, asserting it is too low and underestimates the amount of runoff produced by these areas that then must be infiltrated, evapotranspired, or harvested to prevent its discharge. First, I must point out that I did not follow the usual practice of picking a runoff coefficient from a general table but instead computed it according to a fairly involved procedure outlined on pages 5 and 6 of my Initial Report. The coefficient I calculated is well-supported and calibrated. Moreover, as explained below, my conclusion here is well-supported based on independent factors.

In the City of Seattle cascade inlet study, the catchment area contributing to the cascade inlet was estimated by the City at approximately 10 acres. Land use is mostly single-family residential, although there is some commercial development along an arterial street. While the neighborhood is within the City of Seattle, the lots are fairly large and have relatively extensive lawns for an urban location. The City estimated imperviousness at 40 to 45 percent, mostly consisting of roofs and streets.

During the course of the study, it was noted that a small amount of flow was being measured at the 110th Cascade inlet relative to the quantity of precipitation falling on the 10-acre catchment. Careful observation revealed that water from much of the supposed catchment was not actually reaching the cascade, because many rooftops discharge to unconnected surfaces, subsurface areas, or the sanitary sewer, and water does not easily reach some of the catch basins. All in all, the impervious area actually contributing to the measured flow was estimated to be 0.8-1.0 acre. Additional area may contribute during the largest storms and during very wet conditions.

Figure 1 plots influent runoff volume versus rainfall depth for all 239 storms that occurred during the monitoring period. Several statistical regression techniques were applied to these data, the best-fit lines for two of which are shown in Figure 1. If the flow volumes are converted to water depth across the catchment, then the slope of the fitted line becomes the runoff coefficient; i.e., the ratio of runoff produced to rainfall. All regression methods considered indicate a runoff coefficient of 0.10-0.11, which is equivalent to about 1 acre of directly connected impervious surface with a runoff coefficient of 1.0. That situation, in fact, is what was observed and described above, and this regression analysis lends support to its conclusions.

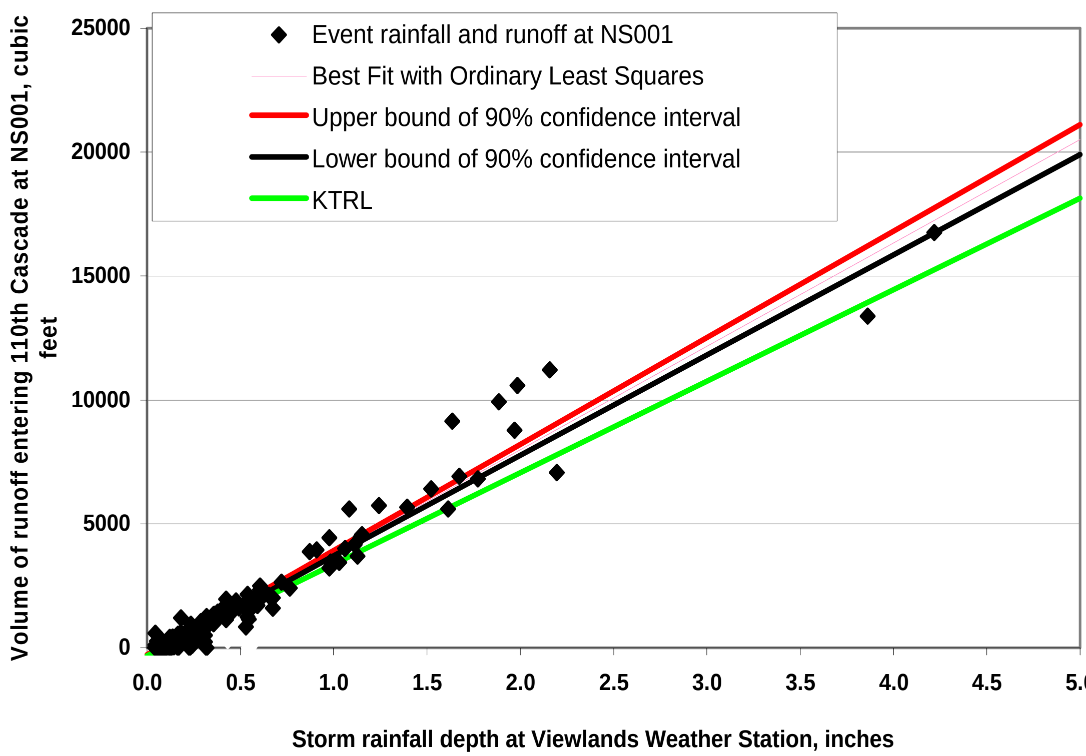

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Figure 1. Scatter Plot of Runoff Volume at the Cascade Inlet Versus Rainfall Depth for All Storms from October 11, 2003, to March 31, 2006 (NS001 is the inlet station; KTRL is the Kendall-Theil-Robust Line.)

Another view of runoff production can be gained by considering the largest storm of record at the inlet station, which occurred on October 19-21, 2003. This storm registered 4.22 inches of rain in 32 hours, with 16,755ft^3 of runoff discharged over the weir. This volume of runoff is equivalent to 0.46 inch spread over the presumed 10-acre basin. This is equivalent to saying that the apparent runoff coefficient was 0.11, or alternatively that the area effectively draining to the station with a runoff coefficient of 1.0 was only 1.1 acre; i.e., 4.22 inches of rain over 1.1 acres is 16,755ft^3. It is clear from these two different methods of assessing runoff production entering the cascade that much less runoff consistently results than would be expected in a highly developed urban catchment. It is hence apparent that much of the basin is not connected to the drainage system leading into the cascade.

Hence the runoff coefficient for this watershed (with a slight majority of pervious area) is just about the same as I estimated for pervious areas in wetter portions of the San Francisco Bay region. Roof drainage disconnection and depression storage, which withholds runoff from reaching catch basins, probably account for the low runoff production by the impervious areas. If the overall runoff coefficient is 0.11, the coefficient for the pervious portion must be much lower than that value, since 40-45 percent of the catchment is impervious and, by direct observation, still channels large amounts of flow to the cascade, even if quite a lot of it is disconnected. I can see no reason why pervious areas on A, B, and C soils in the San Francisco Bay region would have higher runoff coefficients than we demonstrated in this Seattle area on generally C soils. Therefore, once again, as with my infiltration rate and land cover choices, I can strongly support my runoff coefficient values and stand by the analysis based on those selections.

I believe that I have demonstrated, from two independent standpoints, that a runoff coefficient of 0.12 (lower for dryer portions of the region) is a justifiable value for pervious areas. As before, however, even if my analysis were erroneous in some fashion, any error would not disrupt the soundness of my conclusions. On this issue, I have reproduced below a segment from Table 7 of the Initial Report: the portion of the table covering the wetter areas of the region, for which I used a pervious-area runoff coefficient of 0.12 (labeled Table 2 here). The second row in this case shows both not-connected impervious area (NCIA) plus pervious area runoff, as in the original table, and the pervious area runoff production separately. The second, third, and sixth rows compare results for the two runoff coefficient assumptions.

I consulted Table 6.2 in a text by Akan (1993) to get advice on runoff coefficients for pervious areas; these data originally came from the American Society of Civil Engineers. The range given for lawns is from 0.05-0.10 with flat topography (2 percent slope) and sandy soil to 0.25-0.35 for "heavy" soil on a steep slope (7 percent). The heavy soil, average slope (2-7 percent) range is 0.18-0.22. If I am wrong about 0.12 as the most appropriate value, my analyses are probably not off by more than a factor of two, based on Akan's table. Accordingly, I have doubled the pervious area runoff quantities: the second row of the table shows the pervious area runoff amounts for both 0.12 [in brackets] and 0.24 {in braces} runoff coefficients.

The final row in the table shows clearly that doubling the runoff coefficient for pervious land decreases the infiltration capacity only very marginally. While I firmly believe that I am correct about the pervious runoff coefficient's being approximately 0.12, even if this were not so, the evidence indicates that my conclusions regarding the degree of runoff attenuation in each case study would not change.

Table 2. Infiltration and Runoff Volume with 20 Inches/Year Rainfall, 3 Percent Effective Impervious Area (EIA) and All Not-Connected Impervious Areas (NCIA) Draining to Pervious Areas, and Pervious Area Runoff Coefficients (RC) of 0.12 and 0.24

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
EIA runoff (acre-ft/year)	0.52	0.14	0.04	0.10	6.2	0.01
NCIA + pervious area runoff with pervious RC = 0.12 (acre-ft/year) *(with RC = 0.24)* [pervious portion with RC = 0.12] { pervious portion with RC = 0.24}	**11.7** ***(12.4)*** **[0.73]** **{1.46}**	**2.34** ***(2.67)*** **[0.33]** **{0.66}**	**0.64** ***(0.72)*** **[0.08]** **{0.16}**	**1.04** ***(1.36)*** **[0.32]** **{0.64}**	**101.7** ***(116.2)*** **[14.48]** **{28.96}**	**0.14** ***(0.16)*** **[0.02]** **{0.04}**
Total runoff with pervious RC = 0.12 (acre-ft/year) *(with pervious RC = 0.24)*	12.2 *(12.9)*	2.48 *(2.81)*	0.68 *(0.76)*	1.14 *(1.46)*	108.0 *(122.5))*	0.15 *(0.17)*
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.10
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**0.28**
Infiltration potential with pervious RC = 0.12[c] *(with pervious RC = 0.24)*	84% *(79%)*	>100% by a margin of 1.8 times *(>100% by a margin of 1.6 times)*	>100% by a margin of 2.2 times *(>100% by a margin of 1.9 times)*	>100% by a margin of 4.0 times *(>100% by a margin of 3.1 times)*	>100% by a margin of 2.0 times *(>100% by a margin of 1.7 times)*	>100% by a margin of 2.0 times *(>100% by a margin of 1.8 times)*

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single family home;
[b] Based on Chralowicz et al. (2001) according to the schedule described in the Initial Report
[c] The margin is the ratio of estimated infiltration capacity (**row 5**) to runoff production from NCIA + pervious area (**row 2**).

Finally, I have reviewed portions of the Draft Permit language regarding LID and hydromodification. In my experience, a critical element of any successful program to implement LID and hydromodification in a NPDES MS4 permit context is the specification of a clear performance standard. The proposed LID language in the Draft Permit does not include this element. Further, as noted in a study recently completed by the Low Impact Development Center in cooperation with the State Water Resources Control Board—*A Review of Low Impact Development Policies: Removing Institutional Barriers to Adoption* (December 2007)—the maximum extent practicable (MEP) standard lends itself to adoption of clear performance standards in this area, making the absence of this standard particularly problematic. Based on the Draft Permit language regarding LID, and based on my experience in the field, I am unable to discern what level of performance (and concomitant beneficial water resources impact) will result from these provisions, as proposed.

From a scientific and water quality perspective, a specific performance standard is particularly important in places like the San Francisco Bay region because of growing population and increasing development, leading to more impervious cover. The whole idea behind an EIA standard of 3% is that watersheds become impaired as their percentage of impervious surface increases. The San Francisco Bay area is continuing to grow quickly since another 1.7 million inhabitants are expected by 2030.[2] Of course, this also means that many new housing units will have to be constructed (approximately 214,500 by 2014).[3] With 400,000 acres of open land still undeveloped (and much of that within the area covered by the MS4 permit), a maximum allowable EIA of 3% would be a strong start toward improving water quality.[4] My two reports to the Regional Board (as well as this letter) have shown that LID can be implemented feasibly and successfully around San Francisco Bay, and these low-impact designs need a performance standard to be effective.

With respect to hydromodification, I would recommend the following standard: "post-development peak flow rates and volumes shall not exceed the modeled peak flow rates and volumes with pre-European settlement native land cover for all storms from the channel-forming event to the 100-year frequency stream flow." Presently, the Draft Permit requires only that the post-project runoff flow and volume not exceed estimated pre-project (existing) rates and durations. For redevelopment projects where existing flow rates and durations already contribute to hydromodification, with the attendant addition of sediment and pollutant loads and destruction of habitat and riparian vegetation, this standard does little except to endorse the status quo.

I would be pleased to discuss my responses with you and invite you to contact me, should you wish to do so.

Sincerely,

Richard R. Horner

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[2] Greenbelt Alliance, "At Risk: the Bay Area Greenbelt," 2006, p.3.
[3] Association of Bay Area Governments, "Latest News," http://www.abag.ca.gov/planning/housingneeds.
[4] Association of Bay Area Governments, "A Place to Call Home: Housing in the San Francisco Bay Area (2007), at 7; Greenbelt Alliance, At Risk: the Bay Area Greenbelt," 2006, p.4 and p.25.

ATTACHMENT A

Results of Monitoring City of Seattle Natural Drainage System Projects

SEA Street Monitoring

With my colleagues at the University of Washington, I monitored the first of the flat-street installations from 2001 to 2007, with baseline data collected on the preceding drainage system from March 19 to June 18, 2000. This monitoring embraced 35 events totaling 6.32 inches (161mm) of precipitation. The catchment discharged in all events, delivering a total of 8601ft^3 (244m^3) of runoff to the downstream drainage system, which leads to Pipers Creek. As a crude measure of yield, the street generated 1361ft^3 of runoff per inch of rain (1.52m^3 per mm).

Between June 2000 and January 2001, the street and drainage system were rebuilt. The impervious pavement decreased slightly, and the pervious area in the 60-foot City right-of-way was devoted to bioretention cells with soils amended in a fashion very similar to the cascade described in the letter.

Monitoring of the completed SEA Streets project began on January 20, 2001. Over the next approximately two years (through March 31, 2003), the system experienced 162 events producing 76.9 inches (1954mm) of precipitation. The new street discharged runoff during only 11 storms (6.8 percent), yielding 1948ft^3 (55m^3) of runoff, or 25.3ft^3 of runoff per inch of rain (0.028m^3 per mm). This yield is just 1.9 percent of the amount discharged prior to the project's construction.

Flow monitoring continued through June 30, 2007. The last recorded discharge was on December 14, 2002. Rainfall totals at Seattle-Tacoma International Airport for the intervening years were:

2003—41.78 inches (1061mm);
2004—31.10 inches (790mm);
2005—35.44 inches (900mm);
2006—48.82 inches (1240mm); and
2007 (through June 30)—17.51 inches (445mm).

The long-term averages at the airport are 37.99 inches (965mm) annually and 18.92 inches (481mm) for the first six months of the year. Thus, the period since the 2nd Avenue NW natural drainage system last discharged represents rainfalls from somewhat below to much above average. On and about October 20, 2003, the airport gauge registered its highest ever 24-hour rainfall total. Our rain gauge station in the same neighborhood recorded 4.22 inches (107mm) of rain from late on October 19, 2003 to the morning of October 21 (a period of 32.5 hours). During the next month, 3.86 inches (98mm) of rain fell at the gauge location over a 51.25-hour period from November 17 to 19, 2003. Then, in November 2006, Seattle experienced its largest ever monthly rainfall, 15.63 inches (397mm) at the airport. Therefore, the SEA Streets drainage system has managed to halt all discharge of runoff even with exposure to large short- and long-term precipitation quantities.

The SEA Streets site thus has demonstrated a clear ability to store and prevent surface runoff from even more rainfall than occurred during its early years. We can only speculate about the reason for this performance. However, it is likely that the vegetation, as it matures, (1) more effectively intercepts rainfall, after which rainfall can evaporate; (2) assimilates more water into its tissues, for storage and possible transpiration; and (3) assists percolation through the soil by piping water along root structures.

Cascade Monitoring

Our research group monitored the cascade described briefly in the letter during water years 2005 and 2006. Monitoring in this case included both flow and water quality. A summary of monitoring results follows.

- The flow record comprised 235 precipitation events, during or after 186 of which (79 percent) no flow discharged from the cascade. In 117 storms during dry conditions (defined by an antecedent precipitation index), the 93 events that produced less than 0.48 inch (12.2mm) generated no outflow. Of the 24 larger storms, only 14 generated runoff at the outlet. In the wet condition (118 storms), the 66 storms having less than 0.29 inch (7.4mm) of rain were completely infiltrated. Hence, the system is capable of completely attenuating surface runoff from about 0.3 inch (7.6mm) of rain under any condition. Of the 52 remaining events in wet conditions, 35 produced a discharge.

- At least 48 percent of all water entering the system was detained and either infiltrated, evaporated, or transpired. The true number was probably closer to 74 percent, on the basis of the reasonable and demonstrated assumption that the unmeasured contributing basin below the inlet has the same effective contributing area and generates the same flow volume as that above the inlet.

- Of the 49 events with any discharge at all, the outlet peak flow rate was above the rate at the inlet in only 13 events. Based again on the estimate that the true inflow to 110th Cascade was twice that entering at the inlet station, though, it appears that the system reduced peak flow rates in every storm, and usually by over half.

- Water quality monitoring established the reliable effluent concentration (the highest concentration that the cascade is likely to discharge) and the irreducible minimum (the lowest concentration that can be achieved with this practice) for solids, nutrients, metals, and petroleum hydrocarbons.

Event Mean Concentration Ranges Measured in Cascade Discharge Samples and Truncated to Omit Largest and Smallest Values

Water Quality Variable[a]	Number Observed	True Minimum	True Maximum	Truncated Minimum[b]	Truncated Maximum[b]
Total suspended solids	14	9	42	10	40
Total nitrogen	14	0.600	1.600	0.600	1.400
Total phosphorus	14	0.075	0.240	0.089	0.230
Soluble reactive phosphorus	13	0.021	0.110	0.023	0.099
Total copper	11	0.0039	0.0080	0.0039	0.0076
Total zinc	11	0.039	0.11	0.039	0.11
Total lead	11	0.0016	0.0080	0.0018	0.0067
Dissolved copper	14	0.0014	0.0072	0.0017	0.0049
Dissolved zinc	14	0.012	0.067	0.018	0.057
Dissolved lead	14	<0.0010	0.0020	<0.0010	<0.0010
Total hardness	14	6.3	25	7.8	17
Motor oil	14	<0.11	0.33	<0.15	0.33
Diesel	14	<0.05	<0.13	<0.05	<0.11

[a] All values in mg/L.
[b] Truncated values are the second lowest and second highest measured.

- The best conservative estimates of pollutant mass loading reductions over the full monitoring program indicate reductions of no less than 85-90 percent for total suspended solids, lead and motor oil; 60 percent for total nitrogen and total phosphorus; 80 percent for total copper and total zinc; and 50 percent for dissolved copper and zinc. There was no significant decrease in soluble reactive phosphorus loading.

Estimated Reductions in Pollutant Mass Loadings Over the Full Sampling Program at the 110th Cascade

Water Quality Variable[a]	% Reduction Method 1[b]	% Reduction Method 2[b]	% Reduction Method 3[b]	90% confidence interval
Total suspended solids	84	88	86	72 - 91
Total nitrogen	63	65	57	53 - 74
Total phosphorus	63	69	65	49 - 74
Soluble reactive phosphorus	No significant decrease			
Total copper	83	81	78	77 - 88
Total zinc	76	80	79	48 - 85
Total lead	90	87	86	84 - 94
Dissolved copper	67	60	45	50 - 78
Dissolved zinc	55	74	72	21 - 70
Dissolved lead	NA[c]	NA[c]	NA[c]	NA[c]
Total hardness	38	40	26	15 - 55
Motor oil	92	92	92	86 - 97
Diesel	NA[c]	NA[c]	NA[c]	NA[c]

[a] All values in mg/L.
[b] Methods 1, 2, and 3 compute mass loadings using the central tendency of concentrations and total volumes, flow-weighted average concentrations and total volumes, and paired storm concentrations and volumes, respectively.

ATTACHMENT B

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